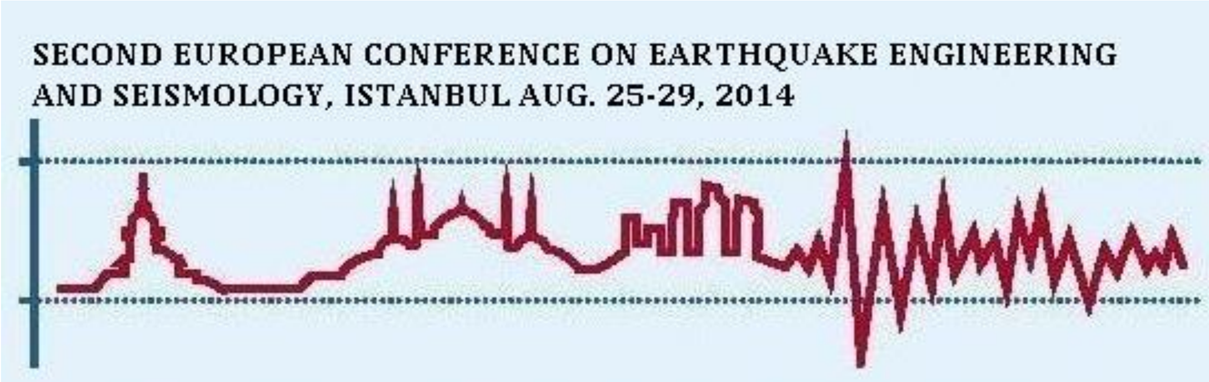

MAPS OF GROUND SHAKING FOR PYRENEES IN FRANCE-SPAIN BORDER

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ABSTRACT

The aim of this study is to produce automatic and fast ground shake maps for Pyrenean earthquakes with a magnitude greater than 3 considering input data from all seismic monitoring agencies operating on both sides of the France-Spain border.

To produce these ground motion maps in the Pyrenean region, specific systems and protocols have been developed and implemented for receiving, in real time, data from seismic and accelerometric stations. These waveform data, temporarily stored in a server, are used in case of detection of an earthquake in the region, for computing ground motion parameters: maximum acceleration, maximum velocity and spectral acceleration for 0.3s, 1s and 3s periods; all of them necessary to compute the shake maps.

Additionally, for the calculation of the maps, the system combines ground motion parameters with macroseismic intensity data, which are automatically computed and sent by several agencies, minutes and/or hours after an earthquake occurs in the region. Ground amplification factors related to the type of ground surface and the different layers in depth are also considered.

INTRODUCTION

In the case of an earthquake that may cause damage, there is a need for quick and automatic products, beyond the traditional data hypocentral location and magnitude, which may be useful to Civil Protection and competent authorities in crisis management, that allow knowing which areas have been subjected to the strongest intensities and the possible damages. For the Pyrenean region, it is necessary that this information is consistent on both sides of the France-Spain border to facilitate a good cooperation between the relevant authorities.

This implies that the effects of a strong earthquake probably will be felt on both sides of the border, as happened in the year 1428 (Catalunya/Cerdanya) or in 1923 (Val d'Aran/Luchonnais). Therefore, the seismic monitoring operative in the region of the Pyrenees requires effective collaboration between national and regional administrations. At present, the seismic monitoring in the

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Pyrenees is guaranteed by four major operators that have been grouped in the project SISPyr (OMP and BRGM on the French side and IGN and ICGC in the Spanish side).

The main objective of the SISPyr project was to implement an automatic system that is capable of producing a sequence of ground motion maps and felt intensities within a few minutes and/or hours following the occurrence of an earthquake. Its results should be readily available on the Internet by posting the maps on a web server and sending emails of a set of maps and data in different formats, including GIS coverages.

Real or near real time data from the agencies involved in seismic monitoring are required for generating ground shake maps. Therefore, it is necessary to establish common procedures, protocols and formats with different partners for the creation and diffusion of these results.

INSTALLING THE SHAKEMAP APPLICATION AT THE ICGC

A ShakeMap is a representation on a map of the ground motion and seismic intensity felt produced by an earthquake. Typically, the parameters defining the ground motion are the peak ground acceleration, the peak ground velocity and the spectral values of the acceleration at certain frequencies depending on the type of building structures in the region. The ShakeMap application has been developed by the USGS (Wald et al., 1999) from the combination of observed data and calculated or estimated data (Worden et al., 2010).

For the generation of maps, network observations, macroseismic surveys, regional knowledge of the attenuation of seismic energy and potential local effects of amplification are used (Fig.1).

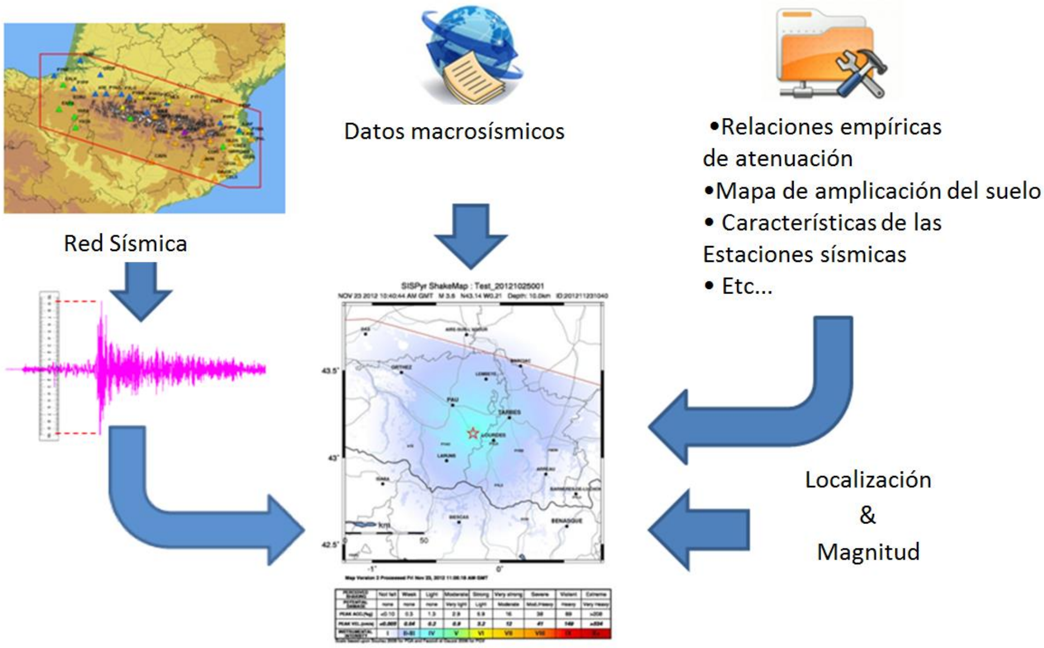


Figure 1. Simplified scheme of the elements involved in the generation of ShakeMaps

The network is the outcome of the reinforcement and homogenization of the already existing cross-border networks with the sharing, in real time, of existing stations and the creation of new broadband stations and accelerometers. A NRT Server stores in real-time three components signals from 50 stations shared by the ICGC, IGN, OMP, IEA and BRGM located in the Pyrenees (Fig.2).

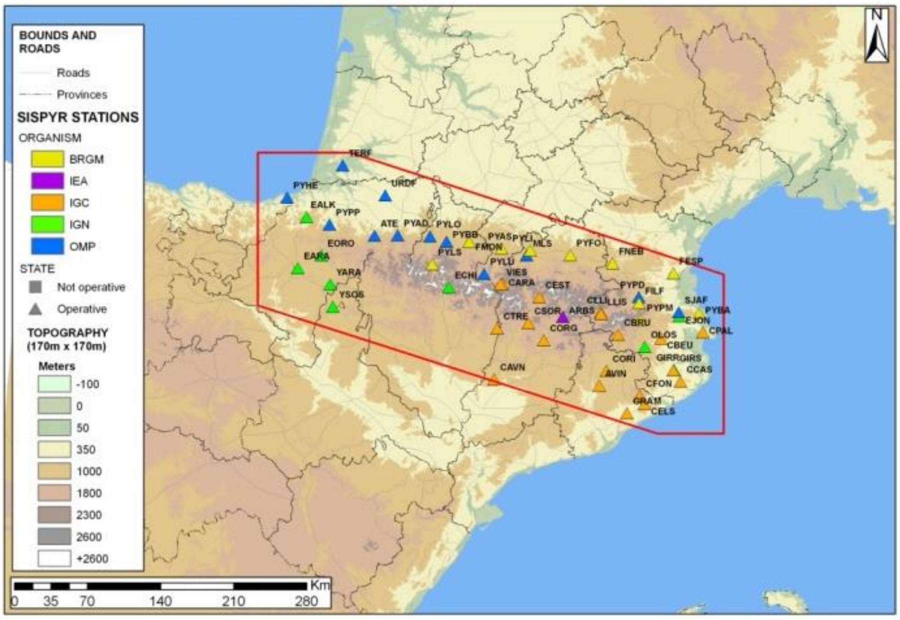


Figure 2. Seismic stations of the SISPyr region

Three agencies contribute to the macroseismic data: IGN and ICGC in Spain and BCSF in France. The information consists of the automatic estimation of the intensity in the EMS scale in towns and municipalities in the area. The first reports can be available in less than an hour.

For the choice of predictive equations of ground motion PGA, PGV and SA parameters at 0.3, 1.0 and 3.0 s from the records of digital signals available of the area have been calculated. They have been compared to a dozen of GMPE (Ground Motion Prediction Equations) from both Spanish and French context and other applicable to the regional seismotectonic context. The selection and classification of relationships have been made using a methodology similar to that of Sherbaum et al. (2004). The finally chosen relationships to be implemented in the ShakeMap application have been the following: Tapia (2006), Akkar and Boomer (2007) and Akkar and Boomer (2010). Fig.3 shows the comparison of the models with regional data from PGA (left) and PGV (right).

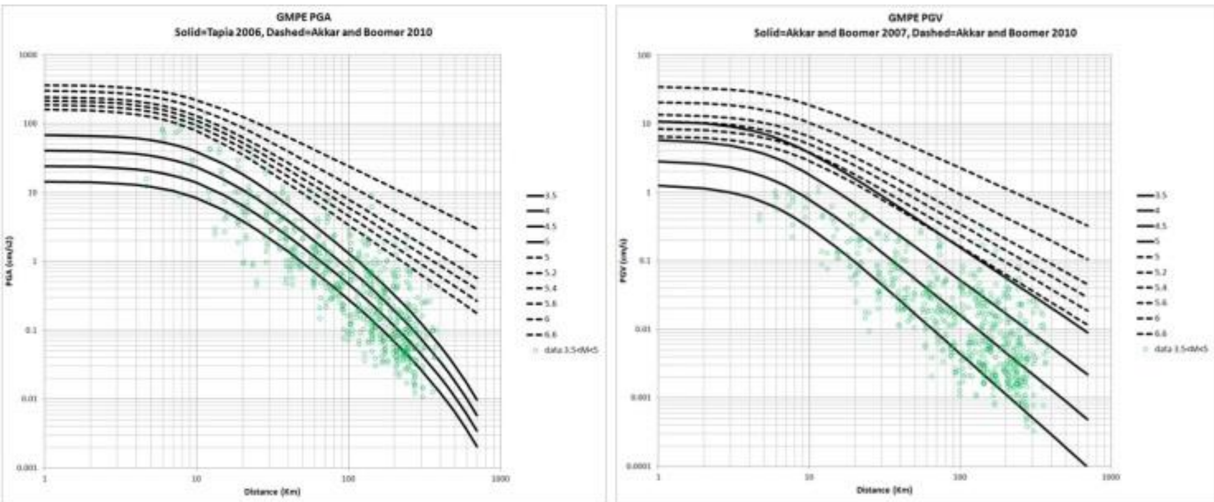


Figure 3. Representation of the selected GMPE’s for PGA (left) and PGV (right)

In the same way, in order to select the Intensity Prediction Equation (IPE) twenty equations have been analysed, being chosen the equation proposed by Goula et al. (2008), based on regional observations obtained in ISARD project (Goula et al., 2007). For equations relating ground motion and intensity data available from 34 earthquakes of M_{ign} = 3.0-5.0 have been used (Susagna et al., 2013). Souriau equations (2006) for PGA vs Intensity, Faccioli and Cauzzi (2006) equation for PGV vs intensity and Kaka and Atkinson (2004) equation for PSA vs intensity have been selected.

To account for local effects the approximation based on the geological and geotechnical conditions (Colas et al., 2012) has been considered rather than based on Vs30 (S-wave velocity in the first 30 m) used in the first ShakeMap application versions. First, a classification of the main superficial lithological units for simplifying and a comparison of the geological map of IGME-BRGM (2009a) and of the quaternary formations IGME-BRGM (2009b) scale 1:400 000 was performed.

This classification is included considering the type of the subsurface formations and the possible thicknesses. These soil columns are characterized using the properties of the soil classes of EC8 (EC8, 2004). The classification of lithologies and the interpretation of soil classes are enhanced using data available from geotechnical surveys in the area and comparing with seismic microzonation studies in the region. The final map is represented in Fig.4.

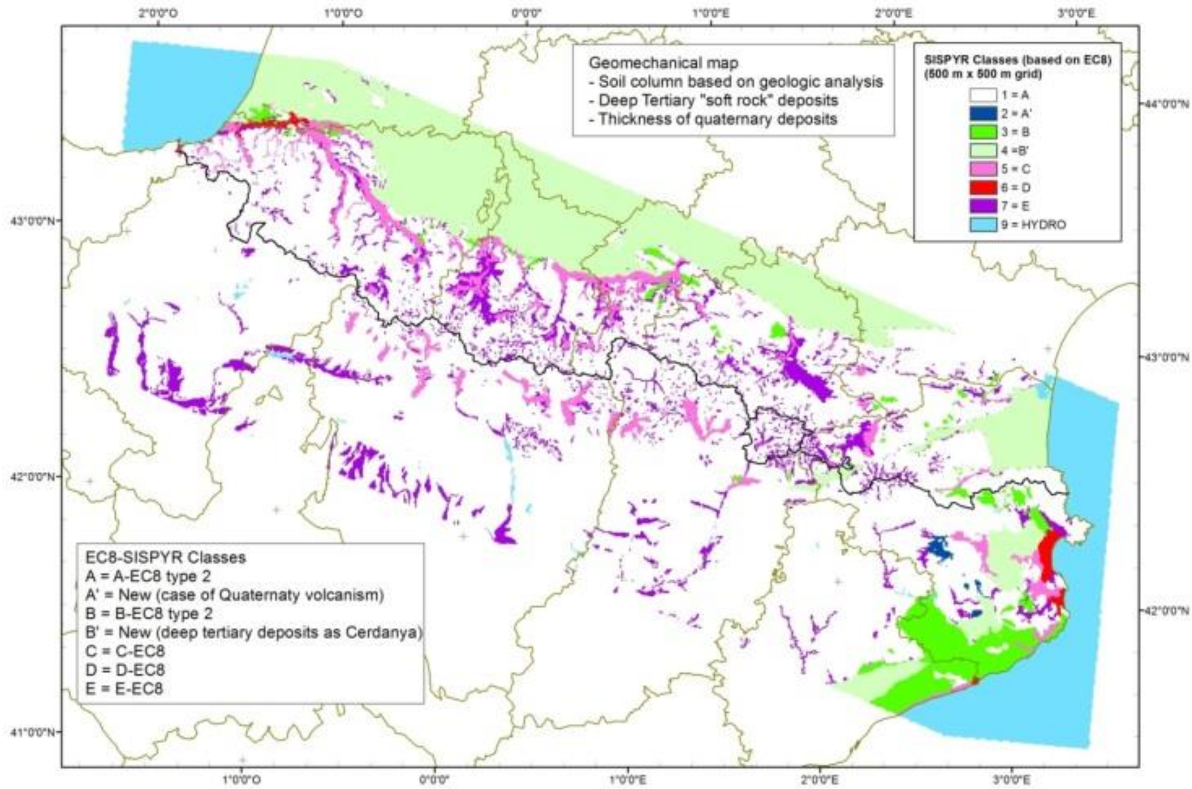


Figure 4. Geomechanical map of the Pyrenean region

In Table 1 are shown the amplification factors Fa (for short periods and PGA) and Fv (PGV and intermediate periods) derived from elastic response spectra proposed for each kind of soil and the PGA in rock less than 0.2g.

Table 1 –Amplification coefficients Fa and Fv associated to modified EC8 soil classes

Soil Class	**Fa**	**Fv**
A	1	1
B	1.35	1.35
B'	1.2	1.7
C	1.5	1.8
D	1.6	1.9
E	1.8	1.4

PUBLICATION OF MAPS IN THE SISPYR WEB

The automatic publication of ShakeMaps on the SISPyr web has been implemented since late 2012. The system is composed of four main parts (Fig.5):

- FTP server for receiving seismic alert messages and macroseismic data,
- Near Real Rime(NRT) server that stores the continuous records of seismic stations in the Pyrenees to be shared among the partners,
- PC with MS Windows system for automatically processing data from the NRT server and
- PC with Linux system for managing the ShakeMap production process.

The ShakeMap process is activated by a seismic alert message sent by the IGN to the FTP containing the automatically calculated location and magnitude of the earthquake that is sent a few minutes after the event has occurred. This Trigger module (Fig.5) can be activated due to an earthquake of Magnitude ≥ 3.0 with epicenter in the Pyrenees zone (Fig.2) or the update of an ongoing process due to the arrival of new macroseismic data.

The system queries the NRT server (DARACOM module in Fig.5) to consult the records for the earthquake seismic stations and DARACOM module immediately calculates the ground motion parameters (PGA, PGV and spectral accelerations) for each component of the stations within a specified minimum epicentral distance.

The macroseismic data are sent to the FTP. The first reports can be available in less than an hour. The process performs a first version with the information available and performs new versions at 5, 30, 60, 90 and 720 minutes after the occurrence of the earthquake to update the ShakeMap estimation using the newly available data.

The Import and Export modules manage the transmission of data to the PC ShakeMap and the ShakeMap products are sent to the web http://www.sispyr.eu/ for publication.

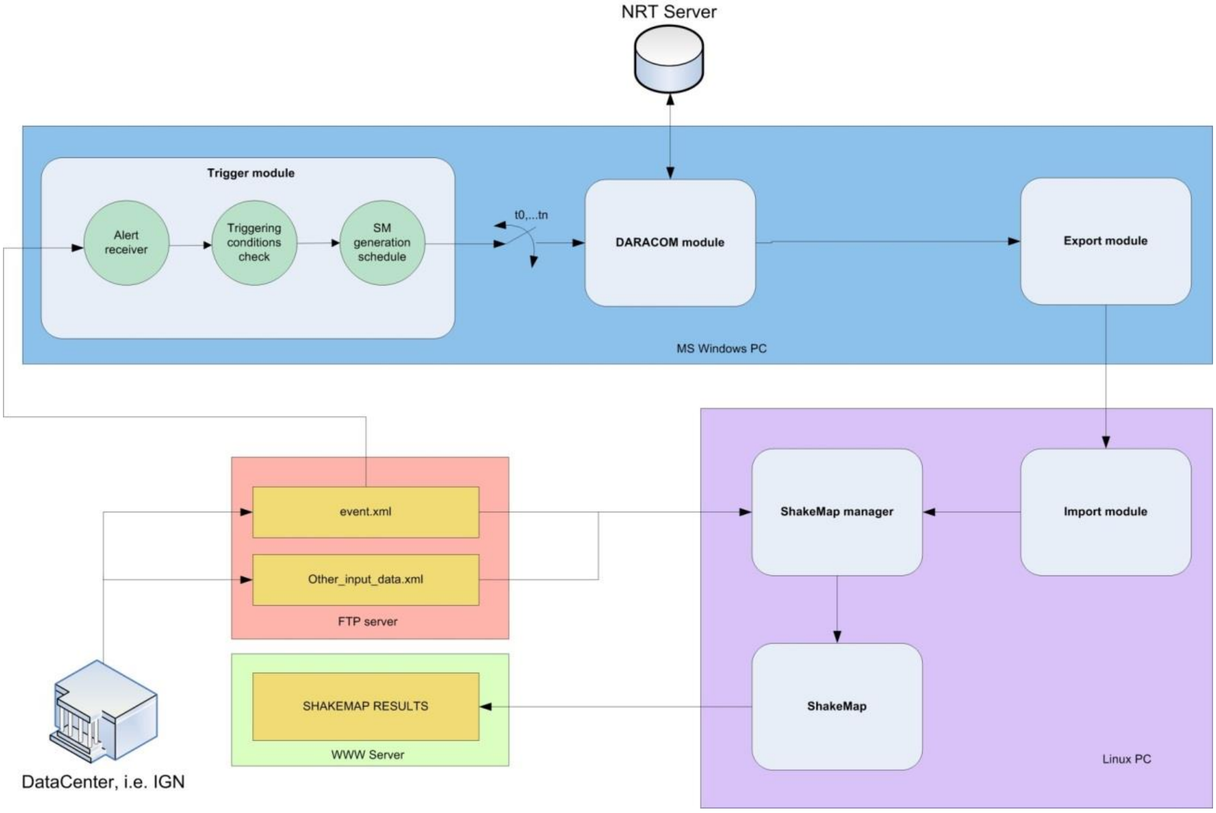
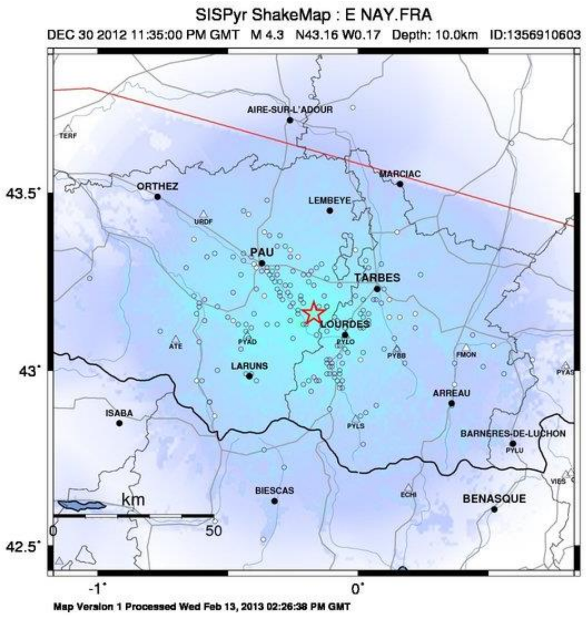


Figure 5. Scheme of the modules included in the ShakeMap automatic system

After eleven months of operation, the ShakeMap process has been activated due to almost twenty earthquakes in the Pyrenees, mostly in the central Pyrenees. Fig.6 shows the ShakeMap of intensities automatically generated for the M4.3 earthquake of December 30, 2012 at 23h 35m (UTC) in the region of Lourdes, the largest in this period. The ShakeMap shows a maximum intensity of IV-

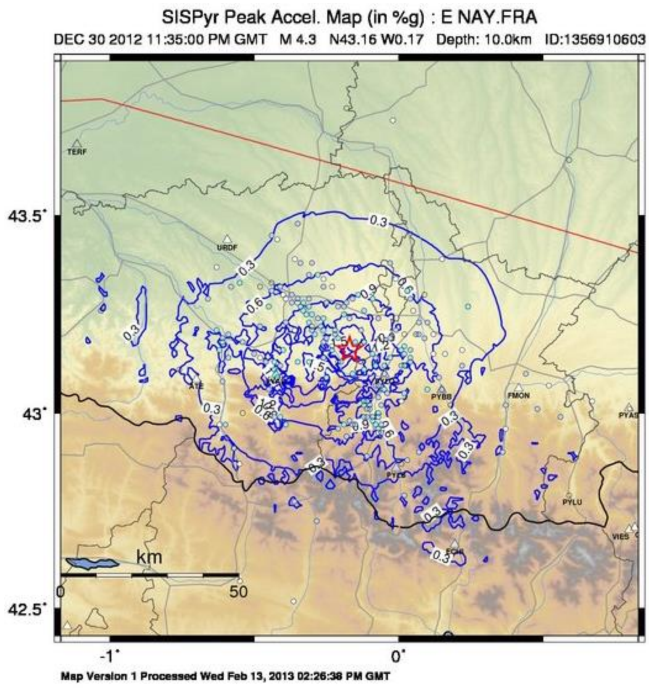
V and IV with intensities about 20 km around the epicenter (red star). The final map is based on 144 values of felt intensities, in circles in the figure obtained by the BCSF (distance between 3 and 160 km) and 44 values of ground motion (in triangles) measured with seismic stations (12 to 290 km away). The legend shows the intensity in colour along with the values of acceleration and velocity of the chosen equivalent correlations. Fig.7 presents the map for peak ground acceleration obtained for the same earthquake.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.10	0.3	1.3	2.9	6.9	16	38	89	>208
PEAK VEL.(cm/s)	<0.005	0.04	0.2	0.9	3.2	12	41	149	>534
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Souriau 2006 for PGA and Faccioli et Gauzzi 2006 for PGV

Figure 6. Intensity map for the earthquake of 30 December 2012. The circles represent data from felt intensities and the triangles those from the seismic stations



PEAK ACC.(%g)	<0.10	0.3	1.3	2.9	6.9	16	38	89	>208
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Souriau, 2006

Figure 7. Peak ground acceleration map for the 30 of December 2012 earthquake

From the web page the user can download the maps of peak velocity, spectral acceleration values at three different periods, as well as, more simplified maps for TV. These maps are available in different formats. Besides from maps, the user can also download the data used, information about the stations, etc.

CONCLUSIONS

The ICGC has been performed the implementation of an automatic representation of different parameters of the ground motion and intensity for earthquakes of magnitude M> 3 in the Pyrenees region by adapting the USGS ShakeMap application.

It has been necessary to select appropriate ground motion predictive equations for the study region. The few existent data that relate the intensity with instrumental parameters in the area have contributed to the analysis.

The geological simplification of formations outcrops and subsoil has allowed estimating a modification of the amplifications of the ground motion following the modified classification EC8.

An important number of stations shared in real time and the pooling of macroseismic data from the two sides of the border has made feasible the implementation of automatic representation system of the ground motion. The maps can be consulted, within a few minutes after an earthquake, at the ICGC and the SISPyr websites.

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